Evaluation of Single- and Dual-Wavelength Radar Rain Retrieval Algorithms by Using Measured DSD

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Objectives

- Development of a more realistic test-bed used for assessment of Ku- and Ka-band dual-λ technique in estimates of hydrometeor's parameters.
- Evaluation of DSD parameterizations: gamma distribution (fixed-μ & μ-Λ) adopted in the retrieval algorithms.
- Analysis of uncertainties and robustness of various algorithms with respect to spatial variations of DSD and PIA errors.
- Identification of appropriate DSD models that provide better estimates of rain rate, attenuation and DSD parameters.

Standard Dual-λ Technique

Differential Frequency Ratio:

$$DFR=10Log_{10}(Z_{Ku}/Z_{Ka})=dBZ(Ku)-dBZ(Ka)$$

Under assumption of gamma DSD,

$$N(D) = N_w f(\mu) \left(\frac{D}{D_m}\right)^{\mu} \exp(-\Lambda D)$$

Thus, $DFR=f(D_m; \mu)$

Procedures become

$DFR \rightarrow D_m$

Z_{Ku} (or Z_{Ka}) & $D_m \rightarrow N_W$

Standard Dual-λ Technique

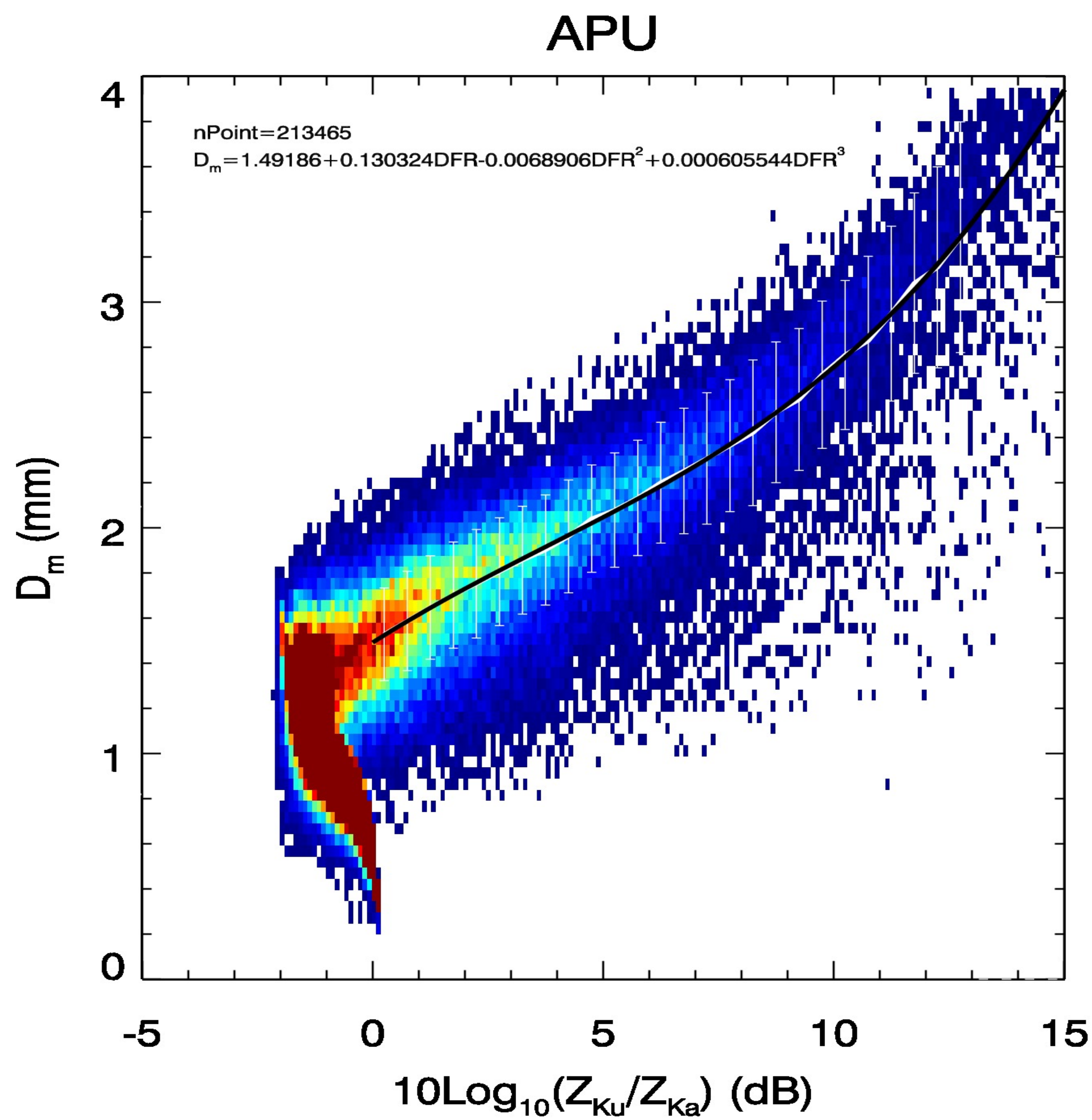
Advantages:

- Fully account for spatial and temporal DSD variations
- Independent of empirical (nominal) relations as used by some techniques

Issues:

- Double solutions of D_m when DFR<0
- Small differences between Z(Ku) and Z(Ka) when DFR<0 or D_m roughly less than 1.5 mm
- DSD model dependent

Example of DFR-D_m Relation



Modified DFR

Defined by

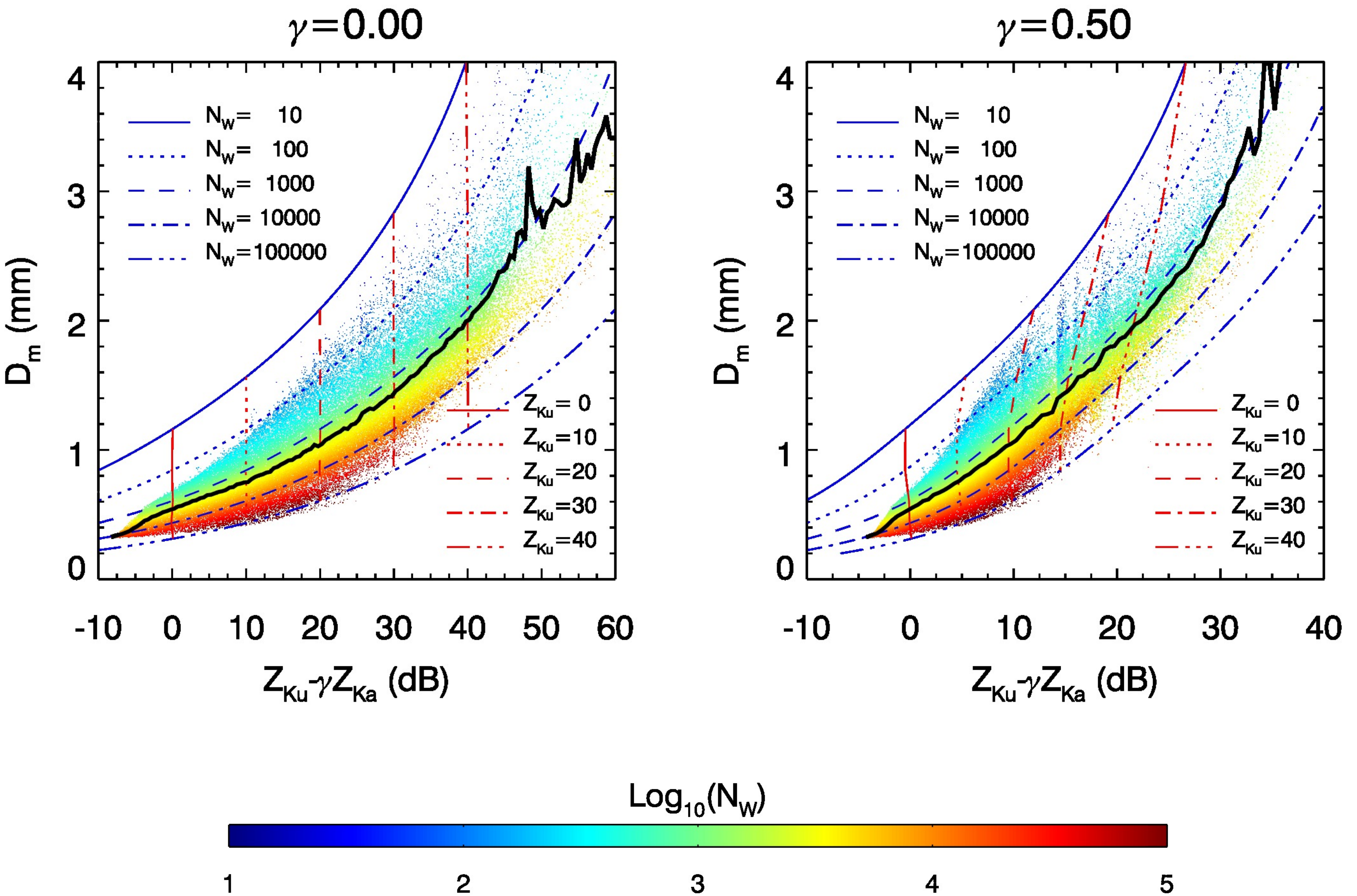
$$DFR^* = Z(Ku) - \gamma Z(Ka) \quad (dB)$$

where γ is from 0 to 1, with special cases in which

$\gamma=0$ (Ku only, single wavelength)

$\gamma=1$ (standard dual-wavelength method)

DFR* depends on not only D_m but also N_W (if $\gamma \neq 1$)



γ=0.00
γ=0.50
N_w= 10
N_w= 100
N_w= 1000
N_w= 10000
N_w=100000
Z_{Ku}= 0
Z_{Ku}=10
Z_{Ku}=20
Z_{Ku}=30
Z_{Ku}=40
D_m (mm)
Z_{Ku}-γZ_{Ka} (dB)
$Log_{10}(N_W)$

GPM DPR-Like APPROCHES:

From R-D_m relation expressed as $$R = \varepsilon^{\tau} a D_m^b \quad (1)$$

From Look-up tables $$R = N_w I_R(D_m, \mu) \quad (2)$$

Then, we have $$N_w = \frac{R}{I_R(D_m, \mu)} = \frac{\varepsilon_k^{\tau} a D_m^b}{I_R(D_m, \mu)} \quad (3)$$

And also, $$Z_e = 10\mathrm{Log}_{10}(N_w) + I_b(D_m, \mu)$$

Substituting (3) into above equation, we obtain

$$Z_e = 10\mathrm{Log}_{10}(\varepsilon_k^{\tau} a) + 10b\mathrm{Log}_{10} D_m - 10\mathrm{Log}_{10} I_R(D_m, \mu) + I_b(D_m, \mu) \quad (4)$$

D_m could uniquely be solved from Eq.(4). Once D_m is determined, R and N_w are obtained from Eq.(1) and (3), respectively. From derived DSD parameters Z(λ) and k(λ) are then computed.

Reference:

Seto, S., T. Iguchi and T. Oki, 2013: The basic performance of a precipitation retrieval algorithm for the Global Precipitation Measurement mission's single/dual frequency radar measurements. *IEEE Trans. Geosci. Remote Sens.*, **51**, 5239–5251.

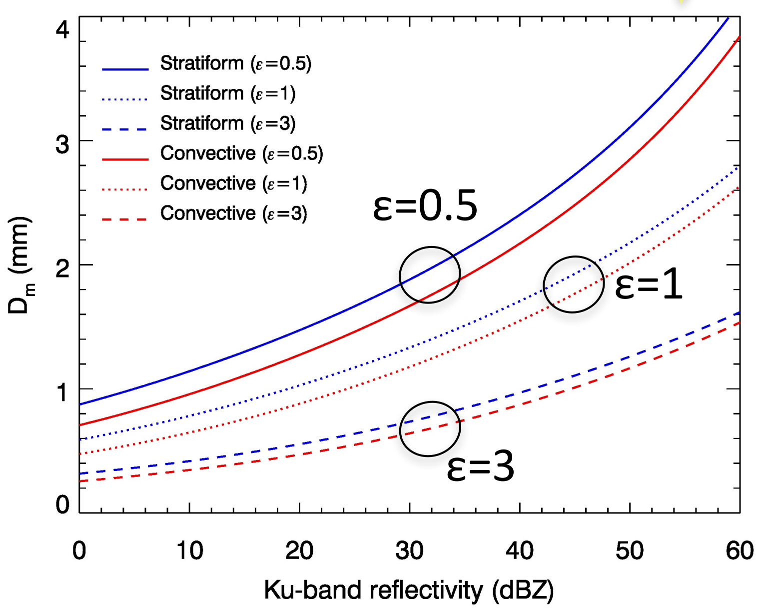
Seto, S., and T. Iguchi, 2015: Intercomparison of attenuation correction methods for the GPM dual-frequency precipitation radar. *J. Atmos. Oceanic Technol.*, **32**, 915-926.

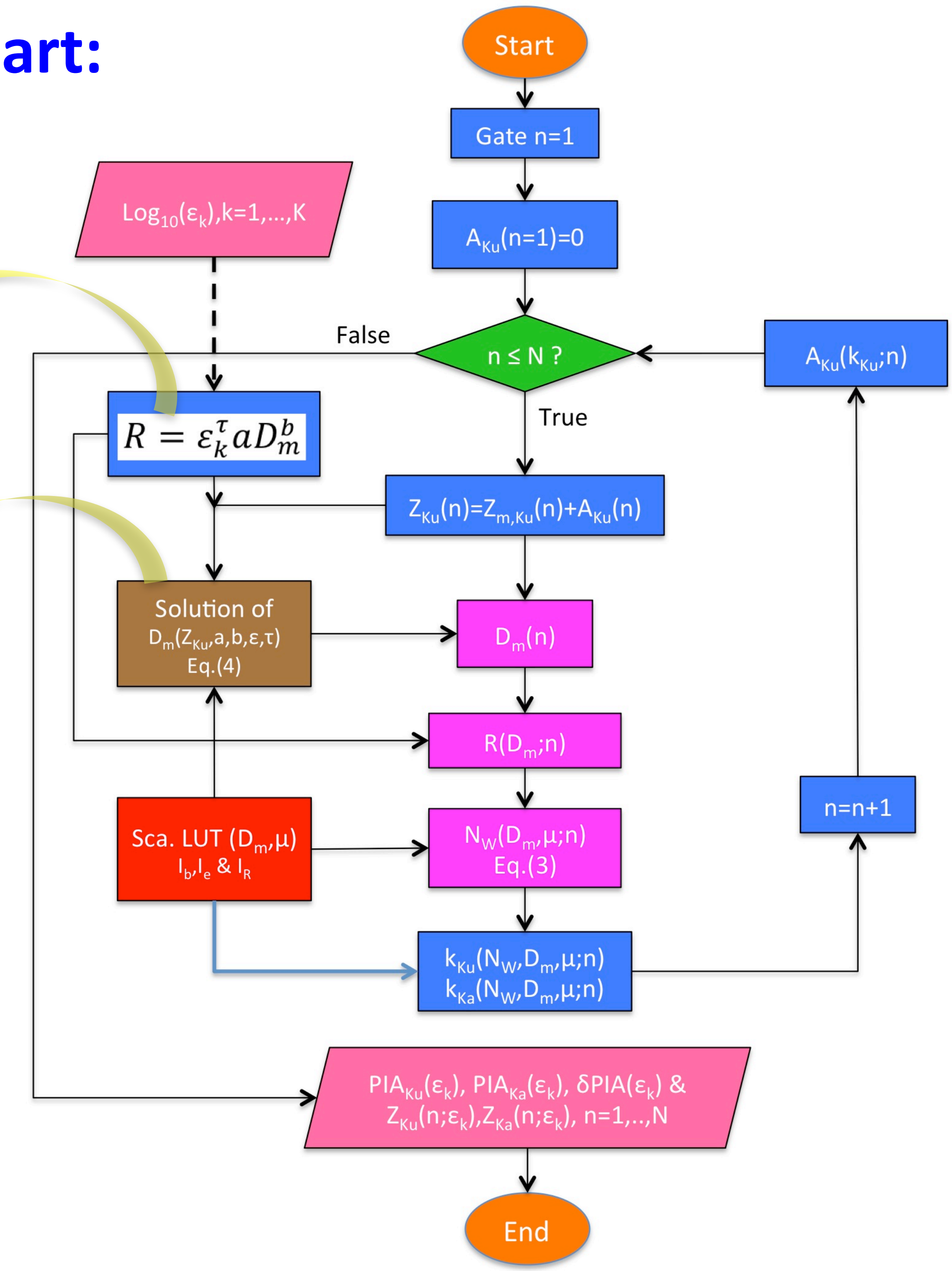
DPR-Like Retrieval Flowchart:

***R*-D_m relation (for GPM/DPR)**

Stratiform: $R = 0.401\varepsilon^{4.649} D_m^{6.131}$

Convective: $R = 1.370\varepsilon^{4.258} D_m^{5.420}$





Finding ε by Optimal Way

Given ε_k, k=1,2,…,K ($0.2 \le \varepsilon_k \le 5$), forward computations are carried out.
ε is chosed so that following conditions are met.

Dual wavelength

$$p_1(\varepsilon)p_2(\varepsilon)p_3(\varepsilon) = \max\,(p_1(\varepsilon_k)p_2(\varepsilon_k)p_3(\varepsilon_k))$$

$$p_1(\varepsilon) = \frac{1}{\sigma_1\sqrt{2\pi}}\exp\left(-\frac{(\log\varepsilon)^2}{2\sigma_1^2}\right)$$

$$p_2(\varepsilon) = \frac{1}{\sqrt{2\pi}}\exp\left(-\frac{(\delta PIA - \delta PIA_{SRT})^2}{2\sigma_2^2}\right)$$

$$p_3(\varepsilon) = \prod_{l=1}^{N}\frac{1}{\sqrt{2\pi}}\exp\left(-\frac{(Z_{m,l,est}^{(Ka)} - Z_{m,l,pbs}^{(Ka)})^2}{2\sigma_3^2}\right)$$

Single wavelength

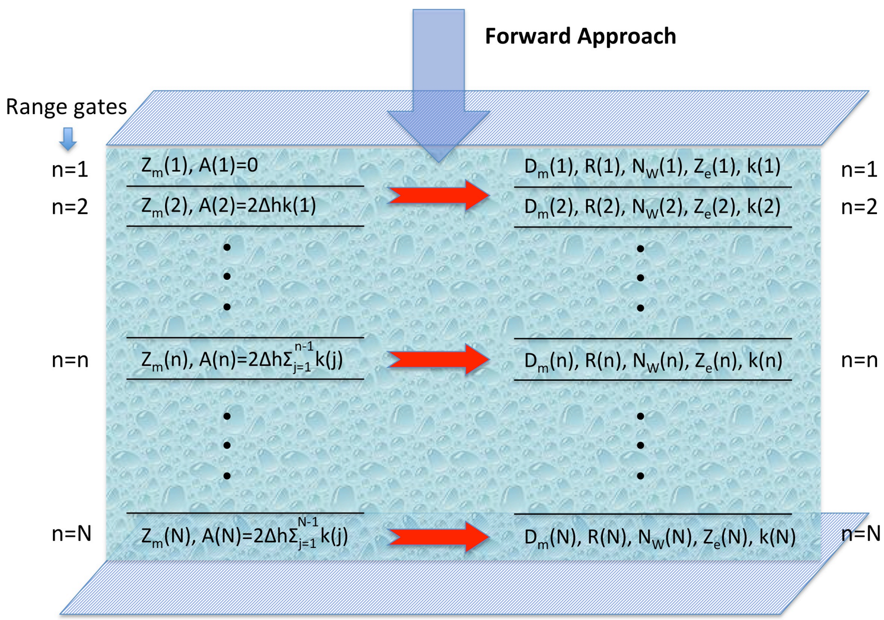
$$p_1(\varepsilon)p_2(\varepsilon) = \max\,(p_1(\varepsilon_k)p_2(\varepsilon_k))$$

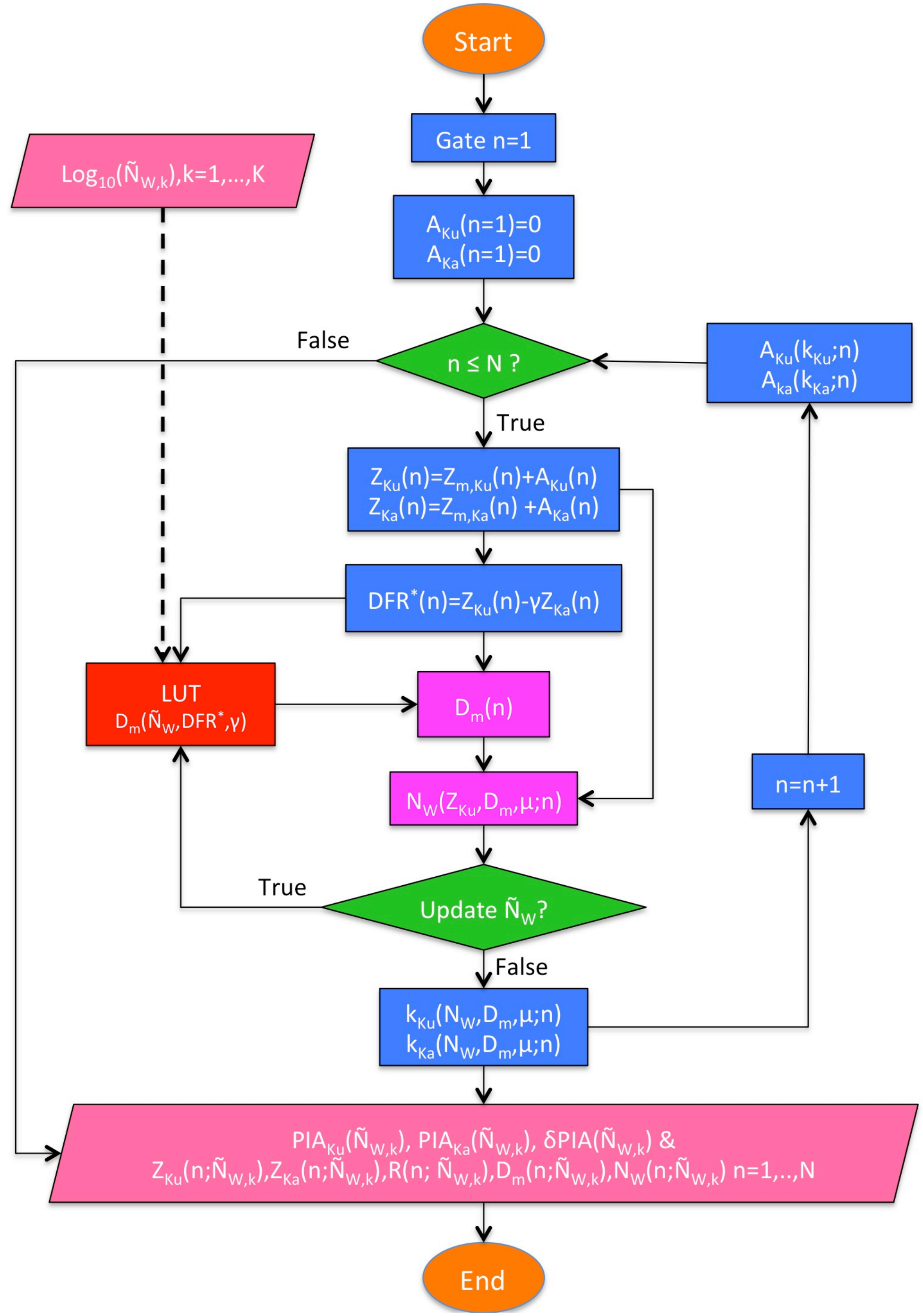
$$p_1(\varepsilon) = \frac{1}{\sigma_1\sqrt{2\pi}}\exp\left(-\frac{(\log\varepsilon)^2}{2\sigma_1^2}\right)$$

$$p_2(\varepsilon) = \frac{1}{\sqrt{2\pi}}\exp\left(-\frac{(PIA - PIA_{SRT})^2}{2\sigma_2^2}\right)$$

Retrieval using Modified DFR*:

$$DFR^* = Z(Ku) - \gamma Z(Ka) \quad (dB)$$





Finding N_w by Optimal Way

Given $\tilde{N}_{w,k}$, k=1,2,…,K ($1 \le \mathrm{Log}_{10}(\tilde{N}_{w,k}) \le 6$), forward computations are carried out. N_w is chosed so that following conditions are met.

Dual wavelength

$$p_1(N_w)p_2(N_w)p_3(N_w) = \max\left(p_1(\tilde{N}_{w,k})p_2(\tilde{N}_{w,k})p_3(\tilde{N}_{w,k})\right)$$

$$p_1(\tilde{N}_{w,k}) = \frac{1}{\sigma_1\sqrt{2\pi}}\exp\left(-\frac{(\log\tilde{N}_{w,k} - 3.45)^2}{2\sigma_1^2}\right)$$

$$p_2(\tilde{N}_{w,k}) = \frac{1}{\sqrt{2\pi}}\exp\left(-\frac{(\delta PIA(\tilde{N}_{w,k}) - \delta PIA_{SRT})^2}{2\sigma_2^2}\right)$$

$$p_3(\tilde{N}_{w,k}) = \prod_{l=1}^{N}\frac{1}{\sqrt{2\pi}}\exp\left(-\frac{(Z_{m,l,est}^{(Ka)}(\tilde{N}_{w,k}) - Z_{m,l,obs}^{(Ka)})^2}{2\sigma_3^2}\right)$$

Single wavelength

$$p_1(N_w)p_2(N_w) = \max\left(p_1(\tilde{N}_{w,k})p_2(\tilde{N}_{w,k})\right)$$

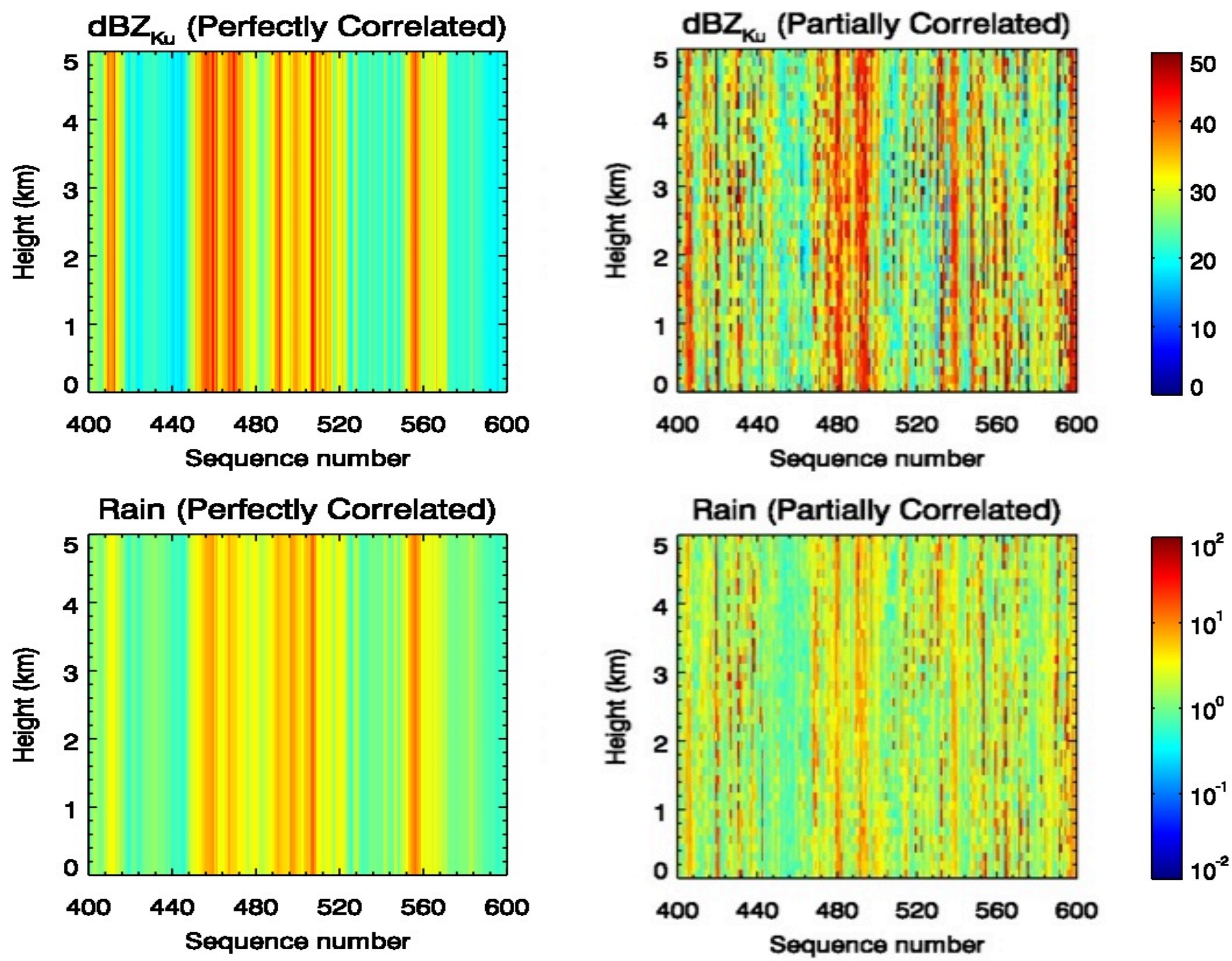
$$p_1(\tilde{N}_{w,k}) = \frac{1}{\sigma_1\sqrt{2\pi}}\exp\left(-\frac{(\log\tilde{N}_{w,k} - 3.45)^2}{2\sigma_1^2}\right)$$

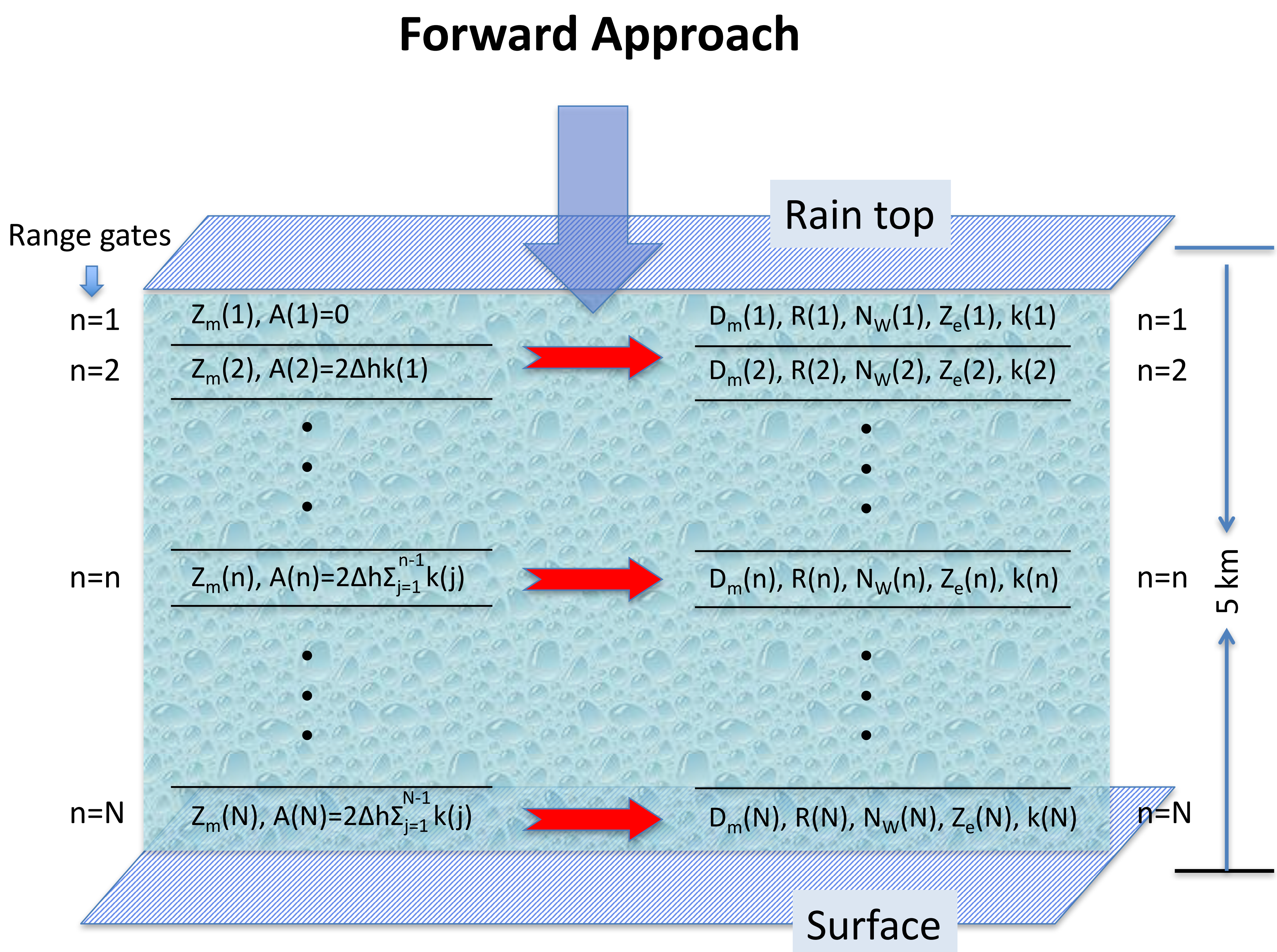
$$p_2(\tilde{N}_{w,k}) = \frac{1}{\sqrt{2\pi}}\exp\left(-\frac{(PIA(\tilde{N}_{w,k}) - PIA_{SRT})^2}{2\sigma_2^2}\right)$$

DSD Measurement Data

	Parsivel (APU)	2DVD
IFloodS	X	X
Wallops	X	X
MC3E	X	
OLYMPEX	X	X

Example of Simulated DSD Profiles

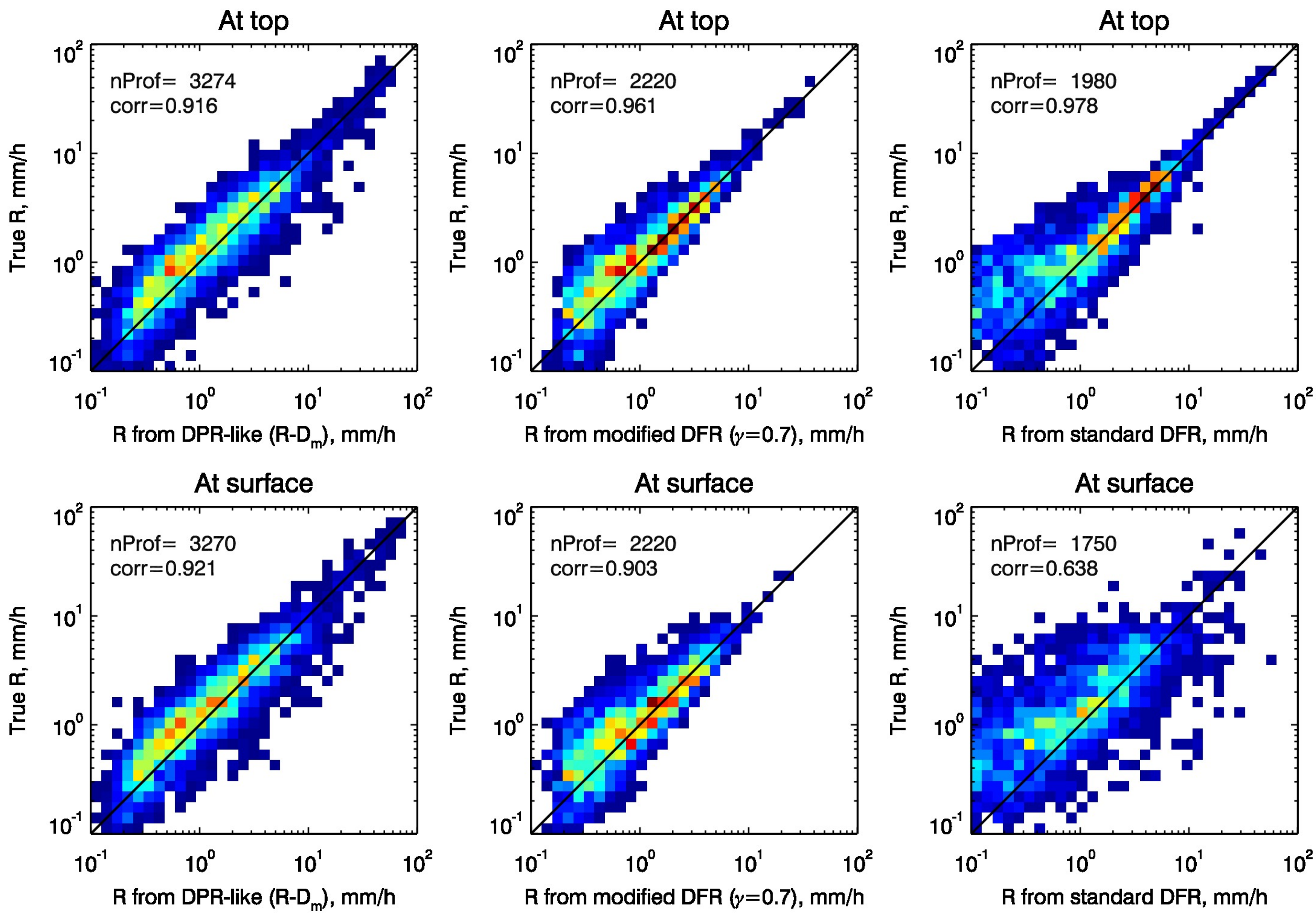


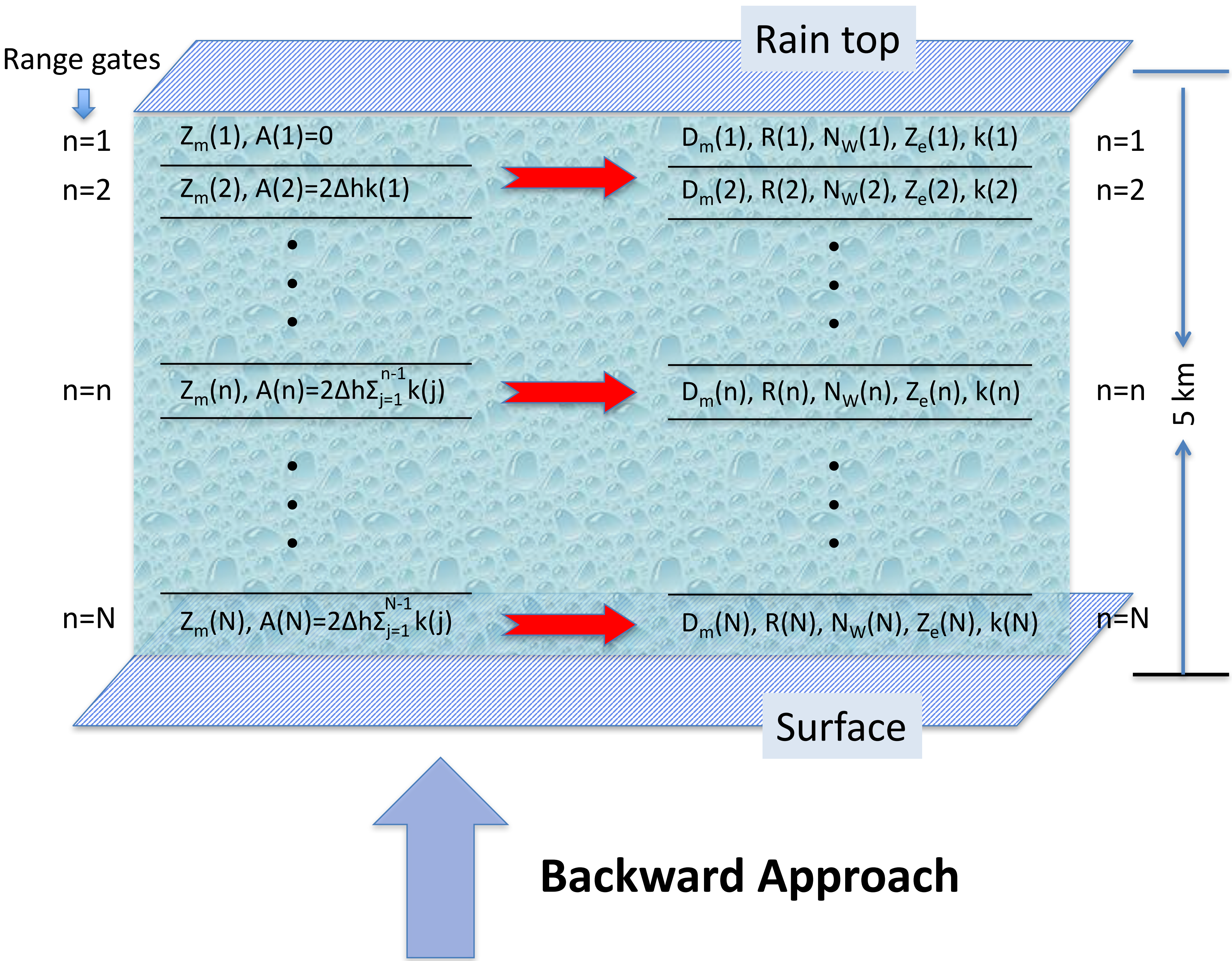


Forward Approach
Rain top
Range gates
n=1
n=2
n=n
n=N
$Z_m(1)$, $A(1)=0$
$Z_m(2)$, $A(2)=2\Delta h k(1)$
$Z_m(n)$, $A(n)=2\Delta h \Sigma_{j=1}^{n-1} k(j)$
$Z_m(N)$, $A(N)=2\Delta h \Sigma_{j=1}^{N-1} k(j)$
$D_m(1)$, $R(1)$, $N_W(1)$, $Z_e(1)$, $k(1)$
$D_m(2)$, $R(2)$, $N_W(2)$, $Z_e(2)$, $k(2)$
$D_m(n)$, $R(n)$, $N_W(n)$, $Z_e(n)$, $k(n)$
$D_m(N)$, $R(N)$, $N_W(N)$, $Z_e(N)$, $k(N)$
n=1
n=2
n=n
n=N
5 km
Surface

Comparisons of Rain from DPR-Like, Modified DFR* and DFR

Non-Uniform DSD Profiles, Std(PIA)=2 dB & Std(δPIA)=0.8 dB (Forward Recursive Approach)

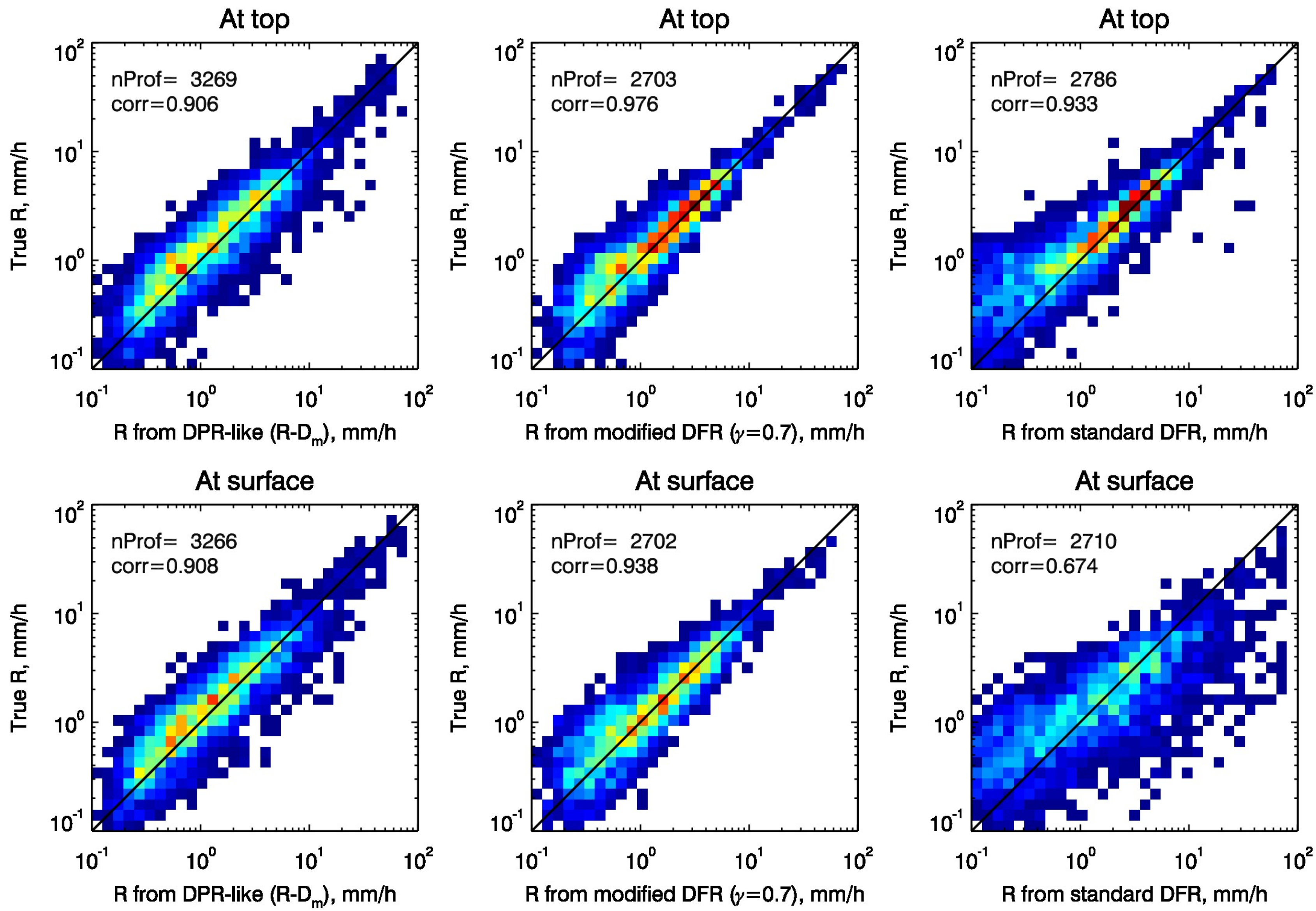




Rain top
Range gates
n=1
$Z_m(1)$, $A(1)=0$
$D_m(1)$, $R(1)$, $N_W(1)$, $Z_e(1)$, $k(1)$
n=1
n=2
$Z_m(2)$, $A(2)=2\Delta h k(1)$
$D_m(2)$, $R(2)$, $N_W(2)$, $Z_e(2)$, $k(2)$
n=2
n=n
$Z_m(n)$, $A(n)=2\Delta h\Sigma_{j=1}^{n-1} k(j)$
$D_m(n)$, $R(n)$, $N_W(n)$, $Z_e(n)$, $k(n)$
n=n
5 km
n=N
$Z_m(N)$, $A(N)=2\Delta h\Sigma_{j=1}^{N-1} k(j)$
$D_m(N)$, $R(N)$, $N_W(N)$, $Z_e(N)$, $k(N)$
n=N
Surface
Backward Approach

Comparisons of Rain from DPR-Like, Modified DFR* and DFR

Non-Uniform Profiles, Std(PIA)=2 dB & Std(δPIA)=0.8 dB (Backward recursive Approach)

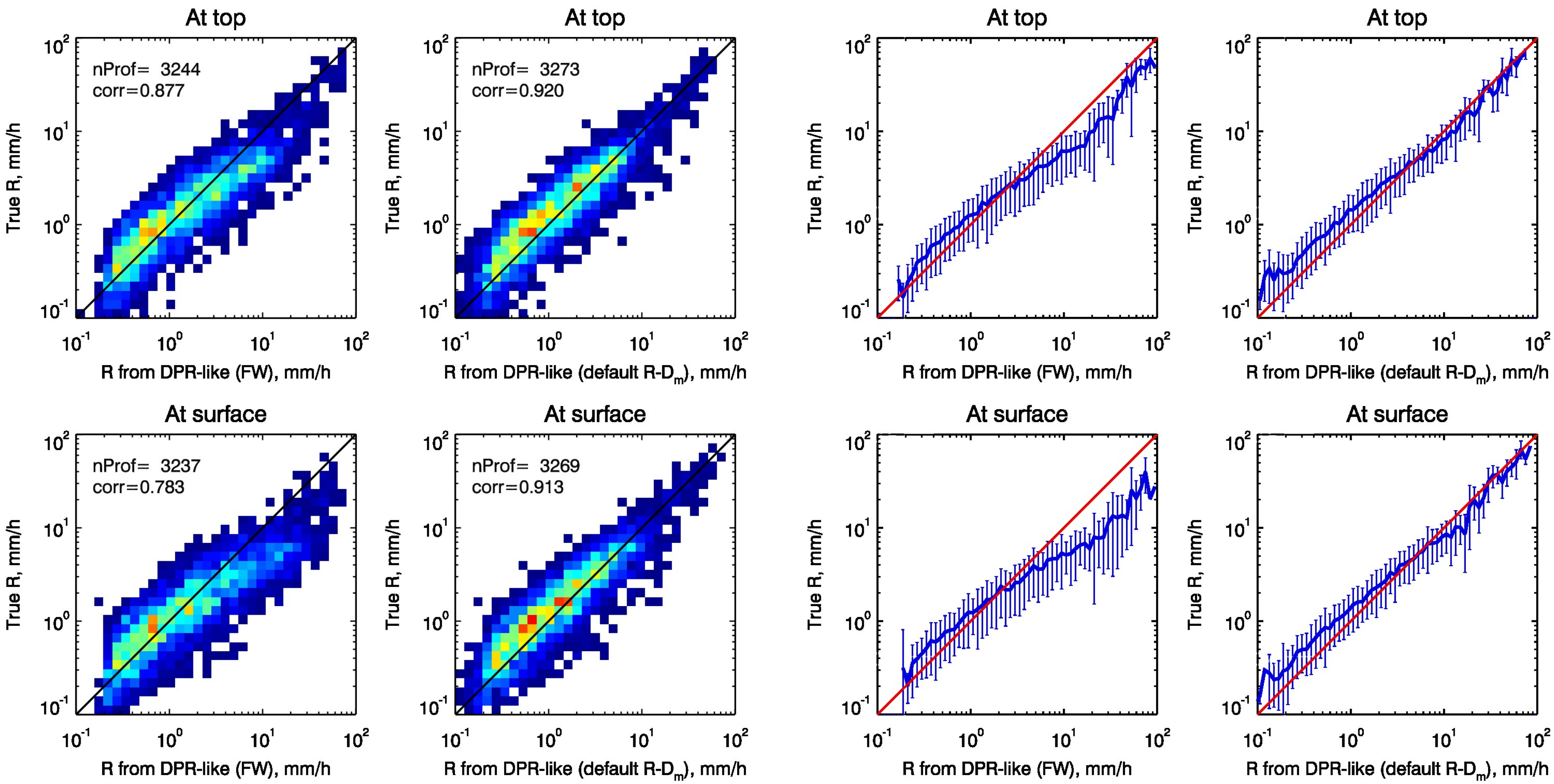


Comparisons of Rain Estimates from Single- and Dual-Wavelength

Non-Uniform DSD Profiles, Std(PIA)=2 dB, DPR-Like Forward Approach

Single-λ vs. Dual-λ

Single-λ vs. Dual-λ



Summary

- A test-bed, comprised of measured DSD, has been used to evaluate several dual-wavelength techniques with particular focus on current DPR-like rain retrieval algorithms.
- The vast majority of DSD data (based on several NASA sponsored field campaigns) are in the range where DFR is close to or less than zero; it leads to large uncertainties in estimates of DSD parameters and rain if the standard dual-wavelength technique (DFR) is used.
- An alternative method, i.e., modified DFR, is implemented in an attempt to avoid double solutions of D_m that the standard DFR method faces. A slight improvement has been noticed in terms of the level of uncertainties.
- Comparisons of DSD and rain retrievals under various simulated errors and assumed vertical DSD structures, show that DPR-like algorithms generally perform fairly well (in both robustness and accuracy) in estimating rain rate and parameters of the DSD.
- Dual-wavelength algorithms outperforms single-wavelength algorithms in achieving better accuracy and less uncertainties.
- A more complete assessment is under way, which include examination of various DSD models and the use of DSD measurements taken from different climatological regions.